



Design and Implementation of Electric Power Patrol Monitoring System Based on Beidou and Mobile Network

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Abstract

Most existing communication technologies used for power inspection systems cannot seamlessly cover the inspection line range. Therefore, the real-time transmission of inspection information and the safety of personnel are difficult to guarantee. Based on current research on electric power inspection and the industry's urgent need for real-time and accurate location information of inspectors, this paper designed and developed an electric power patrol and monitoring system using the Beidou satellite system in conjunction with mobile networks. The problem of patrolling information in blind areas where ground communications cannot be reached in real time is effectively solved through a seamless switching design between Beidou short messages and mobile networks. The short message broadcast and high-precision position information return of inspection personnel were also realized by applying the Beidou multi-mode data transmission module as independently developed. The system took advantage of the user and function-oriented conceptual design and the Browser/Server (B/S)-based architecture design, as well as the combination with the SpringMVC + Spring + MyBatis (SSM) to improve the quality of the development process. Some key functions, such as real-time position display, track playback, user information management, and other functions, are interactive with the implemented visual user interfaces, which fundamentally helps the power monitoring department provide remote visual supervision services. The test results of the core module showed that the system could be used as a supplement to the power inspection and supervision industry, especially for deep mountain valleys, dense forests, and other areas without stable communication signals.

Keywords Electric power patrol inspection · Real time · Beidou short message · SSM · Visual interface

Introduction

Transmission lines are a fundamental infrastructure of the state grid and are an important channel for power transmission (Peng et al. 2015). With the increasing scale of the national power grid, the layout of transmission lines goes deep into the

wilderness, mountain canyons, and other hazardous areas, where the environment is harsh and rarely visited by humans. Traditional power inspection work often requires going into these areas, and the operational mode requires inspecting power transmission facilities one at a time. Therefore, a significant workload is involved in manually recording the patrol inspection information, filling in patrol inspection reports, etc., while the information feedback is often delayed (Tao et al. 2017; Du and Chen 2010). In the case of on-site network failures, the inspection management department does not formulate or dispatch defect elimination tasks nor does it schedule inspection personnel. Therefore, automated and intelligent inspection systems have been considered to realize the scientific and information-based management of power inspection. With the increased investment in power informatization in China's power industry, the software scale of the power industry shows an accelerating development trend, which has become a key field of research at relevant institutions.

When inspecting power transmission lines and checking security defects in areas with poor network environments, power inspectors often fail to timely report inspection and

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location information to the relevant departments due to network problems. Therefore, there are significant hidden dangers in their safety. To date, there are many electric power patrol monitoring systems on the market, most of which use Global Positioning System (GPS) and mobile networks for positioning and communications. At the same time, these can also query power lines, eliminate equipment defects, monitor personnel, manage tasks, and others. However, in blind areas of ground communications, such systems cannot work normally due to the sporadic availability of the mobile network. Therefore, the data cannot be collected or analyzed in real-time, which is not conducive to flexibility in power grid management and control. Even with continuous improvements to the Beidou system, the hardware terminal in specific environments cannot return the inspection information in real-time due to network problems. This paper is based on the Beidou Navigation Satellite System, which was independently developed in China and has a high communication reliability and strong anti-interference ability (Yang 2010), to achieve high-precision positioning of inspectors and design and develop a portable and reliable Beidou multi-mode data transmission module. At the same time, the seamless combination of the Beidou system's unique short message communication technology and mobile network can effectively ensure the real-time transmission of inspection information.

In this paper, we first analyze the requirements of power inspection and monitoring systems, design the system implementation process, and introduce the key technologies used in system implementation. During the software development process, the structures of the foundation support layer, the system model layer, and the presentation layer are divided. The functionalities of the system data management, task information management, map displaying, and path planning are effectively achieved, and some designated functions are examined through experimental testing.

Overall Structure Design of the System

System Function Requirement Analysis

To date, most electric power patrol monitoring systems are based on a geographic information system (GIS) (Dandan 2017), which provides longitude and latitude positioning information with Global Navigation Satellite System (GNSS) and stores the inspection results in a large database to enable information querying. The current inspection and monitoring system includes inspection task management, pole tower management, line management, and information statistics. However, the system lacks real-time online map display functionality. Therefore, the system cannot directly display the location of patrol personnel or ensure their safety. The system also lacks personnel mobilization arrangements and cannot

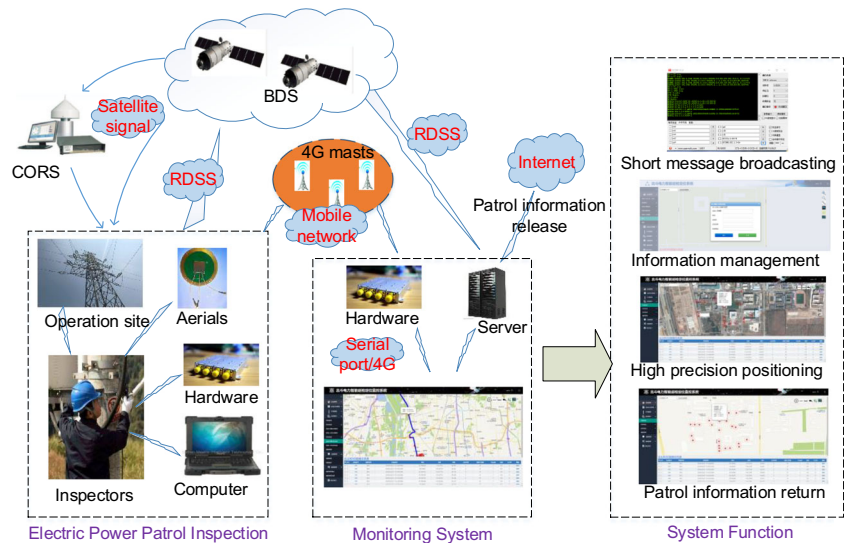
reasonably arrange patrol routes and contents based on the patrol personnel locations, which results in unreasonable patrol arrangements. Finally, the system lacks real-time data return functionality, making it unable to display patrol inspection data or solve problems in real time (Ko et al. 2009; Wang et al. 2016). Based on the development of Internet communication technologies and the major defects of current power inspection system designs, the functional requirements of the system are as follows.

1. Online map display. The goal is to provide vector and image maps for patrol inspectors and vehicles, display their location marks in real-time, enlarge and narrow the maps, measure distances, and analyze the buffer area based on the patrol area. The management center can perform planning and task scheduling according to the distribution and historical tracks of inspectors.
2. Real-time transmission of inspection information. The Radio Navigation Satellite System (RNSS) is used by adopting the transmission technology of Beidou short message communications in combination with mobile networks when available to perform inspection staffing and location monitoring of patrol personnel. The inspection status is transmitted in real time and recorded in the database. When there is no mobile communication signal, the RDSS is used for data transmissions.
3. System management. The system sets a random verification code to log and store the information of managers, inspectors, and vehicles, which includes adding or deleting the name and contact information of a user. Additionally, this also includes patrol task management, line management, and defect management to form a complete system management scheme.

System Concept Analysis

As shown in Fig. 1, the Beidou communication module receives positioning information from the BDS and sends it to the monitoring system together with the electric patrol information entered by staff. In the mobile network coverage area, the information is transmitted to the monitoring system through the 4G network and is sent through the RDSS Beidou short message when there is no mobile network available. The same hardware terminal is configured at the receiving end to receive the short message data, and the data is transmitted to the server through the 4G module. Based on the two-dimensional map (Tianditu), the high-precision positioning module, and the Beidou short message module, the system searches the patrol area on Tianditu and processes the location and patrol information transmitted from the hardware terminal. After the server-side data is

Fig. 1 System concept analysis process



solved, the location results are optimally displayed on the system to realize high-precision positioning of patrol personnel and patrol vehicles. The implementation of tasks and the actual situation of the site allow the monitor terminal to dispatch and command the patrol inspectors and vehicles through the system. In addition, the system can classify, input, edit, query, and summarize the information of patrol personnel, patrol vehicles, patrol facilities, and equipment.

Key Methods of System Implementation

Function Model of Location Algorithm

Kalman Filter Function Model

Kalman filters are optimal estimation algorithms that perform recursive estimations through the state estimation vector and its error covariance to obtain a minimum estimate of the variance (Yan and Deng 2020; Wang et al. 2012). Kalman filtering requires linear conditions, and the following are the basic state and observation equations.

$$X_k = \Phi_{k|k-1}X_{k-1} + \Gamma_{k-1}W_{k-1} \tag{1}$$

$$Z_k = H_kX_k + V_k \tag{2}$$

where k and $k-1$ define time instants, X_k and X_{k-1} are the system state vectors, $\Phi_{k|k-1}$ is the system transition matrix at time $k-1$, Γ_{k-1} is the system noise matrix, W_{k-1} is the system noise vector, Z_k is the observation vector, H_k is the observation matrix, and V_k is the observation noise vector.

Among them, the system noise vector W_k and observation noise vector V_k are uncorrelated white noise with covariance

matrices Q_k and R_k , respectively. The Kalman filter equations are given as:

$$\hat{X}_{k|k-1} = \Phi_{k|k-1}\hat{X}_{k-1} \tag{3}$$

$$\hat{X} = \hat{X}_{k|k-1} + K_k(Z_k - H_k\hat{X}_{k|k-1}) \tag{4}$$

$$K_k = P_{k|k-1}H_k^T(H_kP_{k|k-1}H_k^T + R_k)^{-1} \tag{5}$$

$$P_{k|k-1} = \Phi_{k|k-1}P_{k-1}\Phi_{k|k-1}^T + \Gamma_{k-1}Q_{k-1}\Gamma_{k-1}^T \tag{6}$$

$$P_k = (I - K_kH_k)P_{k|k-1} \tag{7}$$

where \hat{X}_{k-1} is the filter estimation of X_{k-1} , $\hat{X}_{k|k-1}$ is a state prior vector, \hat{X} is the state estimation vector, $P_{k|k-1}$ represents the a priori error covariance matrix, P_k is the estimation mean square error matrix, K_k is the Kalman filter gain matrix, and I is the identity matrix.

GNSS Dynamic Function Model

When establishing the Kalman filter equation, we need the dynamic positioning mathematical model of the moving carrier. Thus, we select the system state vector here as $X = [\delta x \ \delta v_x \ \delta y \ \delta v_y \ \delta z \ \delta v_z \ \Delta t]^T$, where δx , δy , and δz are the position coordinate errors in the Cartesian directions; δv_x , δv_y , and δv_z are the velocity errors; and Δt is the clock error of the receiver.

The system noise vector is $W = [\delta a_x \ \delta j_x \ \delta a_y \ \delta j_y \ \delta a_z \ \delta j_z]^T$, where δa_x , δa_y , and δa_z are the acceleration errors and δj_x , δj_y , and δj_z are the jerk errors. The system state equation can be obtained as Eq. (1) based on these vectors, where $\Phi_{k|k-1}$ and Γ_{k-1} are shown in Eq. (8), and t is the sampling period:

$$\Phi_{k|k-1} = \begin{bmatrix} 1 & t & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & t & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & t & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad \Gamma_{k-1} = \begin{bmatrix} \frac{t^2}{2} & \frac{t^3}{6} & 0 & 0 & 0 & 0 \\ t & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{t^2}{2} & \frac{t^3}{6} & 0 & 0 \\ 0 & 0 & t & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{t^2}{2} & \frac{t^3}{6} \\ 0 & 0 & 0 & 0 & t & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{8}$$

Function Model of GNSS Observation Equation

The pseudorange is used as the observation measurement to solve the following equation:

$$P_r^s = \rho_r^s + c \cdot \Delta t - c \cdot dt^s + \gamma_i \cdot I_{r,1}^s + m^s \cdot T + \varepsilon_r^s \tag{9}$$

where P_r^s is the pseudorange observation, ρ_r^s is the geometric distance from the receiver, $c \cdot \Delta t$ is the receiver clock error, $c \cdot dt^s$ is the satellite clock error, $\gamma_i = f_1^2/f_i^2$ where f_1^2 is the first frequency and f_i^2 is the i^{th} frequency, $I_{r,1}^s$ is the ionospheric delay of the first frequency, m^s is the tropospheric mapping function, T is the zenith tropospheric delay, and ε_r^s is the other error correction.

The first-order linearization of $\rho_r^s = \sqrt{(x-x^s)^2 + (y-y^s)^2 + (z-z^s)^2}$ can be obtained using a Taylor expansion as:

$$\rho_r^s = \rho_{r_0}^s + l^j \delta x + m^j \delta y + n^j \delta z \tag{10}$$

where $\rho_{r_0}^s$ is the satellite ground distance as calculated using approximate coordinates and the other items are shown as follows:

$$\begin{cases} \delta x = x-x_0 \\ \delta y = y-y_0 \\ \delta z = z-z_0 \\ l^j = \frac{x^s-x_0}{\rho_{r_0}^s} \\ m^j = \frac{y^s-y_0}{\rho_{r_0}^s} \\ n^j = \frac{z^s-z_0}{\rho_{r_0}^s} \end{cases} \tag{11}$$

The observed equation can be obtained as Eq. (2), where $Z_k = [L^1 \ L^2 \ \dots \ L^N]$ and L^i is the observation of the pseudo range,

$$H_k = \begin{bmatrix} l^1 & 0 & m^1 & 0 & n^1 & 0 & 1 \\ l^2 & 0 & m^2 & 0 & n^2 & 0 & 1 \\ \dots & 0 & \dots & 0 & \dots & 0 & 1 \\ l^N & 0 & m^N & 0 & n^N & 0 & 1 \end{bmatrix} \tag{12}$$

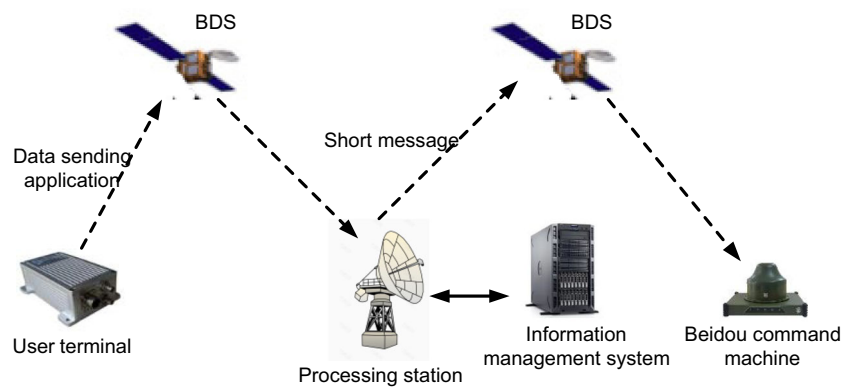
Patrol Data Transmission Mode

The system is set to use a mobile network to communicate between the terminal and the system when the mobile network signal is adequate. When there is no mobile network available, or the information transmission fails, the hardware terminal judges whether the feedback information is abnormal based on the subsequent fields of the internal preset instruction \$BDFKI and automatically switches to the Beidou short message communication mode.

The Beidou system generally has three functions: positioning, timing, and short messaging. The short message is a unique attribute of the Beidou system and is distinct from other navigation systems. That is, there can be two-way information transmission between a satellite positioning terminal and the Beidou satellite ground service station through the satellite signal, which can provide 120 Chinese characters or 1680-bit short message communication services at most times between users and between users and ground center stations. The role of Beidou short messages is important, such as situations that ordinary mobile networks cannot cover (communication base stations are damaged after earthquakes or areas without mobile network coverage, e.g., unmanned areas in the wild or the ocean). The Beidou terminal equipped with a Beidou short message module can conduct emergency communications through short messages. In addition, border patrol, disaster relief, and confidential communications can also be widely used (Ting 2016).

Beidou short message communications are coordinated in three parts: the Beidou positioning terminal, Beidou satellite, and ground terminal (Dan 2015). As shown in Fig. 2, the information flow interaction mode is as follows. The receiver

Fig. 2 Diagram of the Beidou short message communication system



terminal transmits the received position and other information to the ground user machine in the form of short messages based on its specified communication protocol. The communication information is then transmitted to the first-level processing station on the ground through data encryption processing. The message is then analyzed and decrypted using the Beidou information management system in the background of the processing station, which is compiled and encrypted twice. The ground processing station forwards the information to the Beidou satellite in the form of short messages. After receiving the secondary encrypted short message, the Beidou satellite directly forwards it to the command and management machine of the management user. After decryption and compilation, the short message information is transmitted to the user system.

SSM Framework

In the software design, it is necessary to reasonably use layers to follow the design principles of high cohesion and low coupling. When developing and controlling the software layers, it is necessary to ensure that the framework functions are considered. This system uses SpringMVC to process the page logic, selects the persistence layer framework (MyBatis), and integrates it with Spring.

SpringMVC is a Java-based lightweight web framework that implements the Web MVC design pattern request-driven concept (Yujie 2011). Thus, it uses the MVC architecture pattern to decouple responsibilities from the web layer. Due to the request-driven process, this utilizes a request-level response. The model and design framework help simplify daily work development. The SpringMVC framework is designed to facilitate web development. MyBatis is a persistence layer framework that supports database customization, stored procedures, and advanced mapping (Dandan et al. 2014). Distinct from the traditional database connection mode, MyBatis does not require JDBC code nor does it need to use manually set parameters to obtain the database data. Its core competitiveness is that it can more easily obtain and execute SQL statements and write them, which improves the

efficiency of software product development. Spring is a lightweight container framework for the inversion of control (IOC) and aspect-oriented programming (AOP) container framework (Li 2016). It can load bean so that it is not necessary to initialize a class each time it is used, while the keyword “new” is rarely used. The SSM framework is the current mainstream enterprise architecture scheme, which ensures the system has advantages including maintainability, scalability, and portability. This is especially suitable for power inspection systems with rapid function updates and multi-system use.

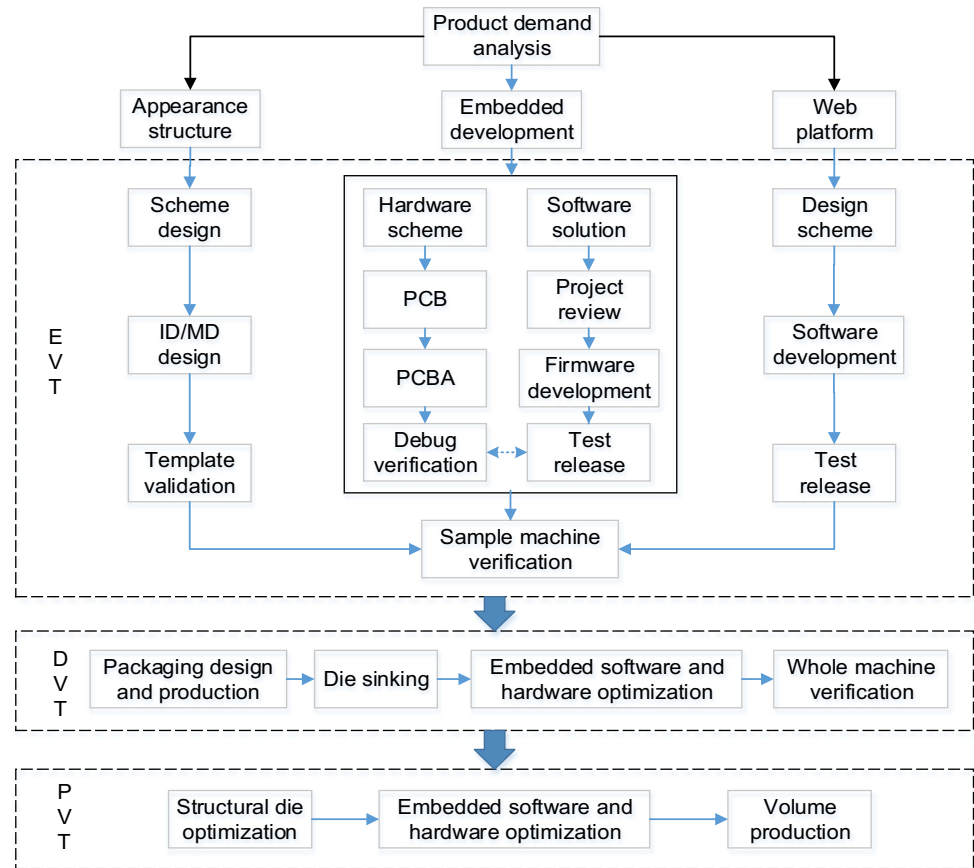
The power intelligent inspection system adopts the Browser/Server (B/S) architecture and is developed in the MyEclipse environment based on Java on the Win10 operating system. Taking the SpringMVC + Spring + MyBatis (SSM) (Yuxiang 2017) as the framework of the system, the requirements are transformed into specific models, and the reusable code is encapsulated into JavaBeans with java basic objects. Finally, the service interface is developed to connect with the JavaServer Pages (JSP), and the business logic is completed using Spring.

Design of Beidou Multi-mode Data Transmission Module

The development of hardware products needs specific processes and strict checks (Yanhua 2019; Zhang 2018). The Beidou multi-mode data transmission module and hardware terminal of the system are developed synchronously from the three routes of appearance. These are the structure, embedded development of software and hardware, and the web platform after a detailed analysis of the power patrol inspection requirements. The hardware terminal passes through the engineering verification test (EVT), design verification test (DVT), process verification test (PVT), and other stages of testing work. This finally forms the current product to put into use. Figure 3 shows the development process of the Beidou multi-mode data transmission module.

The purpose of the EVT stage is to verify the engineering prototype. The web platform defines the data protocol in the hardware communication part and decouples the development

Fig. 3 Module design flow diagram



of the device end and the web platform through the simulation terminal. The development can then be completely independent. The hardware layout can be performed after the industrial design (ID) and mechanical design (MD). However, the hardware scheme and schematic diagram are first created. The embedded software realizes the development of the application in the simulation environment. After the hardware is complete, the software development is continued in firmware or is debugged. Finally, the program is burned, and the prototype is assembled and verified.

The DVT stage is a necessary aspect of hardware production as it mainly includes mold testing, electronic performance, and appearance testing. The entire machine is assembled and tested in accordance with production standards, and a comprehensive test report is generated. If there are problems in the product testing, the embedded software and hardware are optimized, and the entire machine test is performed again.

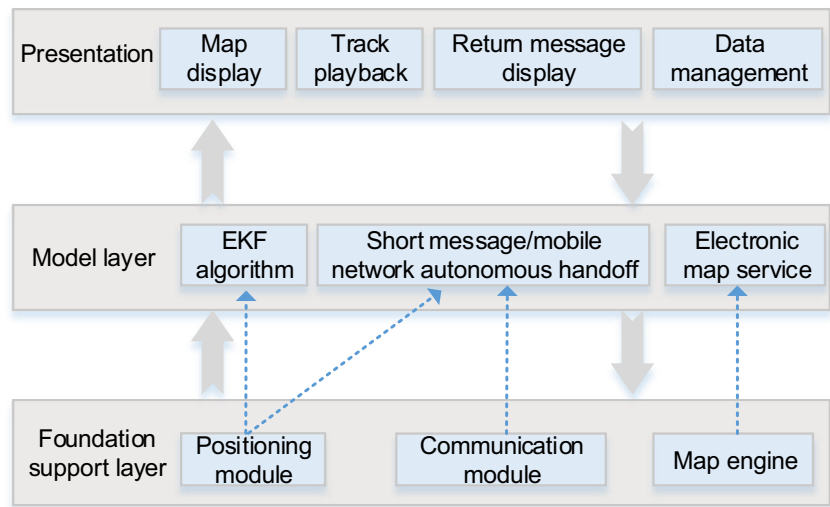
The PVT stage is a type of product hardware test, which mainly verifies the function realization status, stability, and reliability of the new model. At this stage, we only need to address some small problems, such as the uneven structure joints, hardware frame adjustments, and component position adjustment or replacement. Finally, the data as needed for mass production of the mold, printed circuit board (PCB), bill of material (BOM), etc., are confirmed.

The Beidou multi-mode data transmission module is designed in strict accordance with the above processes. The hardware adopts the Beidou baseband chip and integrates the radio determination satellite system (RDSS) radio frequency transceiver chip, power amplifier chip, baseband circuit, STM32 processor, etc. The Altium Designer is used to design and simulate the PCB, which uses Keil, STM32Cubemx, and other approaches to develop the embedded software program. We tested and implemented the RDSS transceiver, modulator and demodulator, and passive location of the Beidou B1 and GPS L1.

System Implementation

A typical power inspection system consists of two parts: the hand-held terminal and the monitoring platform (Zhiling 2019; Chen et al. 2014). This system relies primarily on the highly efficient and stable data source of sensors, such as the Beidou multi-mode data transmission module, which realizes fast and accurate positioning of patrol inspection based on the comprehensive positioning algorithm. The overall architecture of the system end consists of three parts: the foundation support layer, model layer, and presentation layer (Fig. 4). The relevant interfaces are defined between each part and decouple

Fig. 4 System architecture composition



the functional modules. The interactions between the database and the server are more concise, which gives the patrol system good scalability and low maintenance costs.

Foundation Support Layer

The foundation support layer is the bottom part of the system architecture. The hardware terminal relies primarily on the communication unit to capture and collect the data, which is the link between the terminal and the inspection center. The Beidou multi-mode data transmission module is used to collect and forward the positioning information and transfer the short message information. Combining the Beidou satellite navigation and positioning technology seamlessly provides the geographic information system (GIS) and Internet technology, the geographic location, and the operational direction and speed of vehicles and UAVs. This could be used for circuit inspection and short message emergency positioning when there are no communication signals. The hardware terminal is also equipped with 4G and Beidou short message communication modules. When a strong mobile network signal is available, the 4G communication module is used to transmit the patrol information. When the mobile network signal is poor, the Beidou short message communication module is used to send the patrol information, which can realize normal communications in complex network environments. As shown in Fig. 5, we transmit and receive short message information and receive an improved satellite signal when the antenna is directed to the south to realize terminal self-positioning. The monitoring end uses the “Tianditu” of the National Platform for Common Geospatial Information Services to provide the application programming interface (API) and online service resources for the application program. This cuts the high cost of processing and maintaining the public geographic framework data and the bottom geographic information

service, which greatly reduces the time to develop GIS application systems or websites.

System Model Layer

The model layer is in the middle of the system architecture, which is mainly responsible for providing positioning results and information returned by the hardware terminals for the presentation layer, which is the core component of the entire system. The positioning algorithm is one of the core aspects of satellite navigation. A set of suitable positioning algorithms directly determines the positioning results, which greatly affects the track information displayed in the presentation layer



Fig. 5 Experimental test and data collection

and navigation service quality of the system. The extended Kalman filter (EKF) approach is applied to the navigation and positioning algorithms. The dynamic model of the system is established by collecting a large amount of Beidou data, such as time, longitude and latitude, speed, and direction angle. The selection of the initial filtering value and the system noise is studied using the EKF, which shows it effectively reduces the random interference of the BDS positioning signal, improves the dynamic positioning accuracy, improves the practicability of the navigation and positioning system, and provides high-precision location services for the power inspection and monitoring system. The system then develops the STM32 microcontroller unit (MCU) control program based on the Keil Vision5. The algorithm in the C language is burnt into the system using the J-link. The program is then debugged, which includes checking the variables, memory, and registers, and a time tracking analysis is performed. The data are finally broadcast to the system presentation layer.

System Presentation Layer

As the top level of the system architecture design, the presentation layer primarily provides intuitive and fast information services for power inspection managers and is the application implementation of the overall business logic design. Based on the functional requirements, the system can fulfill the geographical position display for operators, the management and supervision of the inspection work, and the scheduling arrangement when the inspection system can receive and analyze the terminal data. To follow the basic principles of the system's functional practicability, technological advancement, and aesthetics of the interface, the electric power monitoring system's login interface (Fig. 6) and the main interface (Fig. 7) are designed. The first-level menus for the level management, inspection operations, and other operations along

with the sub-level menus for specific functions and some core functions are designed as follows.

- (1) Map display: the system calls the Tianmap service to locate the exact location of patrol vehicles and personnel in real time, as well as the speed, status, and direction of patrol vehicles based on the information returned by the terminal. Two-dimensional and image maps can then be displayed in the general interface, and the inspection area can be enlarged or reduced while performing distance measurements and buffer analyses on the map.
- (2) Track playback: the system automatically saves the route of patrol vehicles and inspectors at any time in the past for location query and track playback.
- (3) Return information display: patrol inspectors return real-time location and patrol information to the system. After the information screening and processing, the system displays feedback information in the table below the map.
- (4) Data management: the system database is equipped with a user data table to manage user authorities; the user management function is utilized to add, modify, and delete personnel and vehicle information.

Experiments

To test the performance of the patrol inspection and positioning equipment and the feasibility of the monitoring system, this paper considered a campus as the test site. The non-mobile network communication environment was simulated through the upper computer software, and the basic functions, such as the Beidou high-precision positioning, Beidou short message broadcasting, and positioning information display, were emphatically tested.

Figure 8 shows images of the PCB and product. The module adopted a light aluminum shell for easy carrying. The

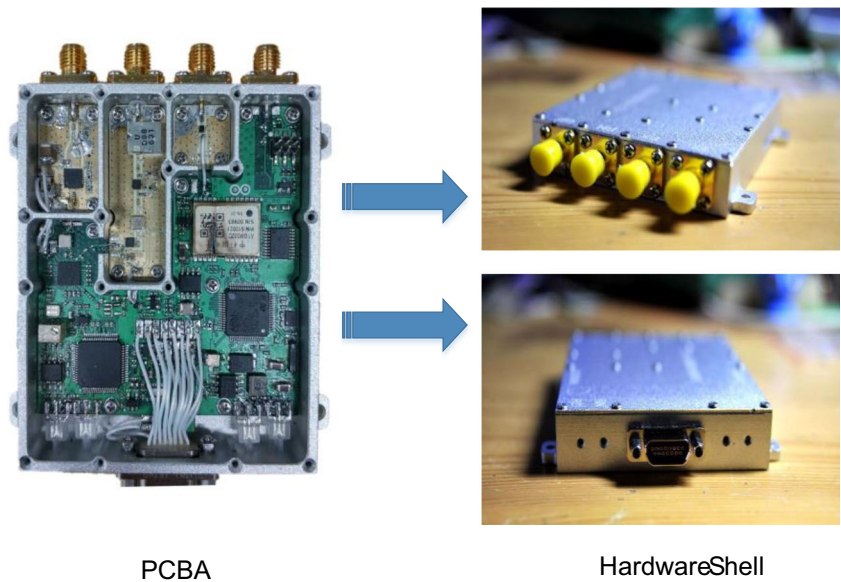
Fig. 6 Login interface of the proposed program





Fig. 7 Main interface of the proposed program

Fig. 8 Beidou multi-mode data transmission module



Beidou antenna, 4G antenna, DB15 serial port, and indicator lights were set at the interface. The relevant performance parameters are summarized in Table 1.

We first tested the performance of the equipment, as shown in Fig. 9. The serial port assistant indicates the following. The

\$GNGGA shows that the positioning function of the Beidou module is normal; the \$BDICI shows that the user card function is normal; the \$BDBSI shows that the RDSS receiving status is normal; the \$BDFKI shows that the output feedback information of the Beidou terminal is normal; and the

Table 1 Summary of the module performance parameters

Mode	Parameter	Value
RDSS	Transmitting frequency	1615.7 MHz
	Receiving frequency	2491.75 MHz
RNSS	Receiving frequency	Beidou B1, GPS L1
	Location mode	Single system; Joint location
RDSS	Receiving sensitivity	-127.6 dBm
	Time of recapture after losing satellite	≤ 1 s
RNSS	First start time	Cold start 32 s, Hot start 1 s
	Data update rate	1 Hz (customizable)
RDSS	Output power	≥ 37 dBm
	Sensitivity	Capture - 145 dBm, Trace - 160 dBm

Fig. 9 Equipment test



\$SCCTXA shows that the peripheral communication application is normal. After the hardware terminal passes inspection, the system function test began. In this process, the terminal faced as far south as possible to receive and send short messages. The location accuracy and information reception were verified through an open area, trees, and building block areas. As shown in Fig. 10, during the simulation of personnel patrol on campus, the short message information was stable at a frequency of 1 Hz. Figure 11 shows the real-time track view of the patrol vehicles.

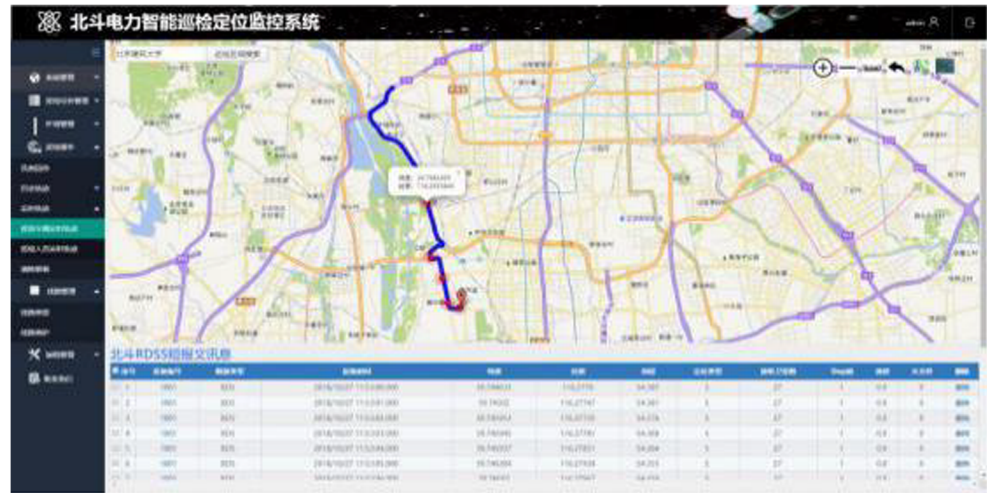
After testing, the differential positioning accuracy of the Beidou multi-mode data transmission module was

approximately 3 cm (shown in Fig. 12), and meter-level accuracy was obtained for single point positioning, which indicates that the system can provide accurate position information for power patrol operations and can secure patrol personnel without requiring a mobile network. Other functions, such as personnel information storage, positioning information display, and patrol information exchange during the patrol operation, were successfully achieved. We also solved several existing industrial issues, including real-time feedback on power patrol information in environments without mobile networks, personnel safety management, and work scheduling problems with precise operations.



Fig. 10 Short message information

Fig. 11 Vehicle real-time track



Conclusion

Based on the current shortcomings of the electric power inspection system in China, the proposed design adopts the advantages of current electric power inspection system schemes, combines the advantages of the B/S system architecture and SSM framework, adopts the self-developed Beidou multi-mode data transmission module, introduces key technologies such as the EKF algorithm and Beidou short message communication, and designs and realizes an electric power patrol monitoring system based on Beidou and mobile networks. The system primarily solves the following problems. (1) The

patrol information from mobile network communications in blind areas cannot be posted to the server-side in real time, and (2) the visual interface design for real-time position display, track playback, and information management function modules. To ensure the smooth implementation of precise personnel positioning, timely information feedback and remote command to dispatch managers in multiple scenarios are needed. Based on the experimental test results, the positioning accuracy of a single point is at the meter level and approaches 3 cm when differential data are connected. This fully meets the positioning requirements of current inspection personnel. With the development of fusion positioning and the

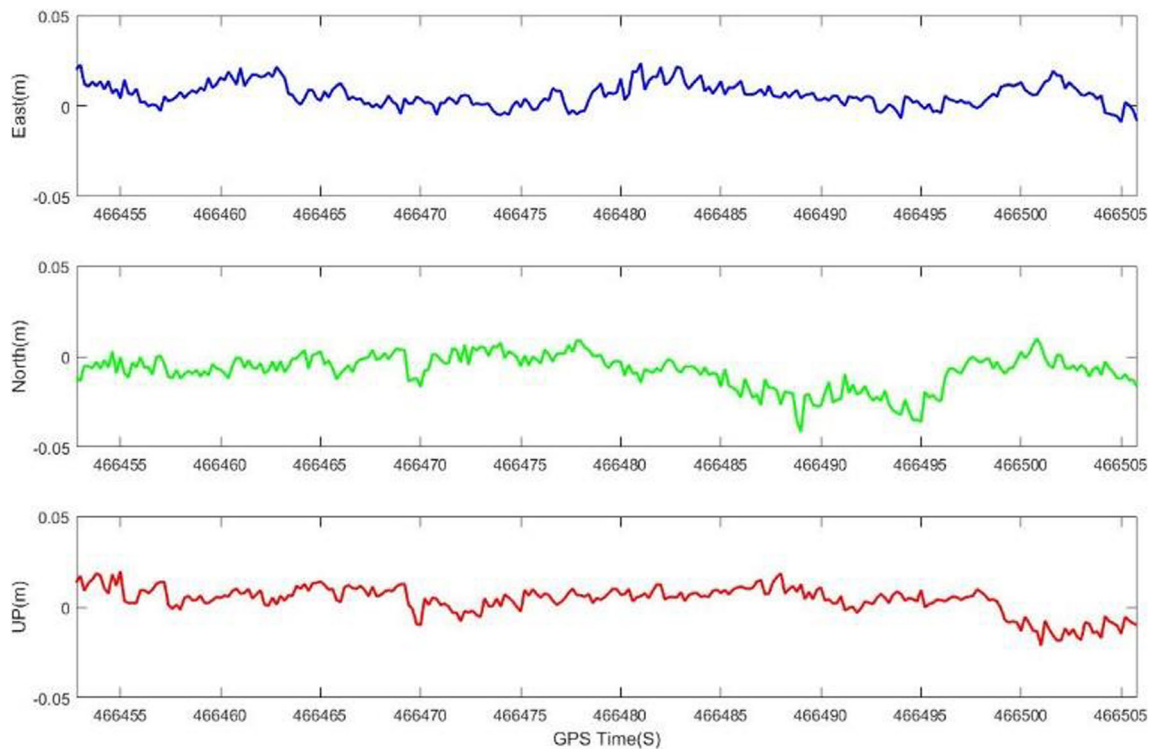


Fig. 12 Differential positioning accuracy

comprehensive completion of the Beidou-III system, the next step is to access the handbooks of the hardware system and coordinate multi-sensor fusion positioning to optimize the interactivity of various parts of the system to make the power inspection more efficient, precise, and economical.

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Authors' Contributions Yuntian Brian Bai conceived the idea and designed the system scheme; Nan Guo drafted the manuscript, designed the experiments, and developed the system; Xin Cheng audited the figures and tested the system; Dongwei Tian contributed to modify the paper. All authors have participated in the approval of the final version.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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